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(54) **ELECTRIC SYSTEM COMPRISING A LOAD DRIVING APPARATUS BY AUTO-RECOVERY MODE, AND METHOD OF OPERATING THE APPARATUS**

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H02H 9/00	(2006.01)
H02H 3/02	(2006.01)
H02H 9/02	(2006.01)

(52) **U.S. Cl.**

CPC ***G05F 1/462*** (2013.01); ***H02H 1/043*** (2013.01); ***H02H 3/025*** (2013.01); ***H02H 9/002*** (2013.01); *H02H 9/025* (2013.01)

(58) **Field of Classification Search**

CPC G05F 1/573; H02H 1/043; H02H 3/025

See application file for complete search history.

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(57) **ABSTRACT**

A driver for an electric load includes a power device having a control terminal and an output terminal for an output current, and a control module. The control module is configured to drive the power device in an auto-recovery mode by switching between activation and deactivation in the occurrence of an overcurrent condition, wherein the output current reaches a threshold current. The control module is also configured to evaluate a first time interval between a time wherein the overcurrent condition occurs, and a first time, and generate a limit signal when the time interval is equal to a time threshold. The power device is driven in a switching-off condition at least as a function of the limit signal.

25 Claims, 7 Drawing Sheets

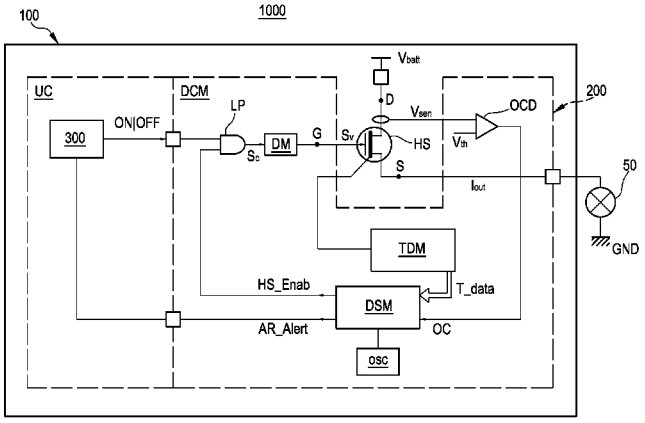

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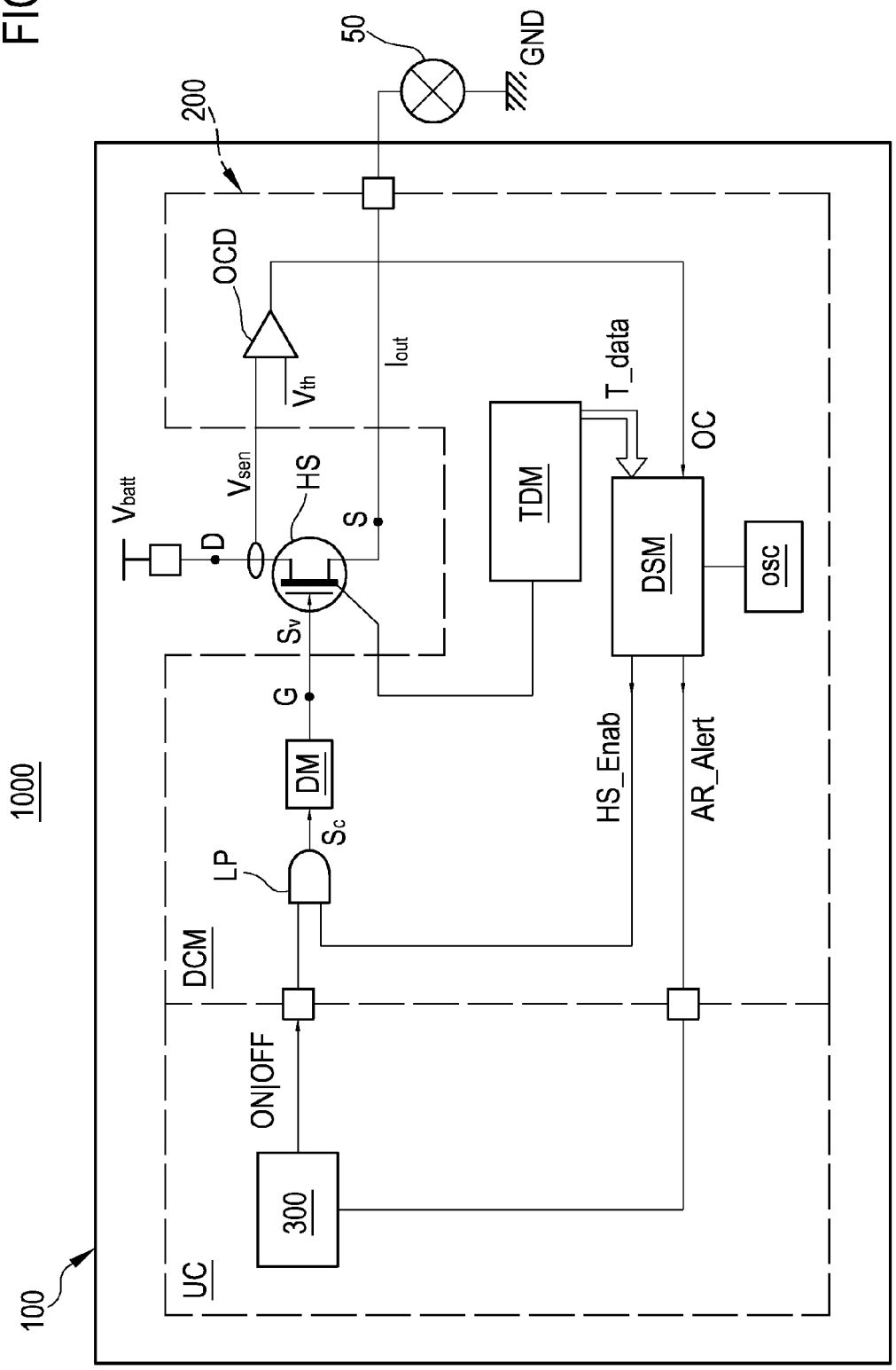
FIG.1


50
GND
200
OCD
V_{th}
I_{out}
T_data
OC
V_{batt}
V_{sen}
HS
S
D
TDM
DSM
osc
S_v
G
DM
S_c
LP
HS_Enab
AR_Alert
1000
DCM
ON/OFF
300
UC
100

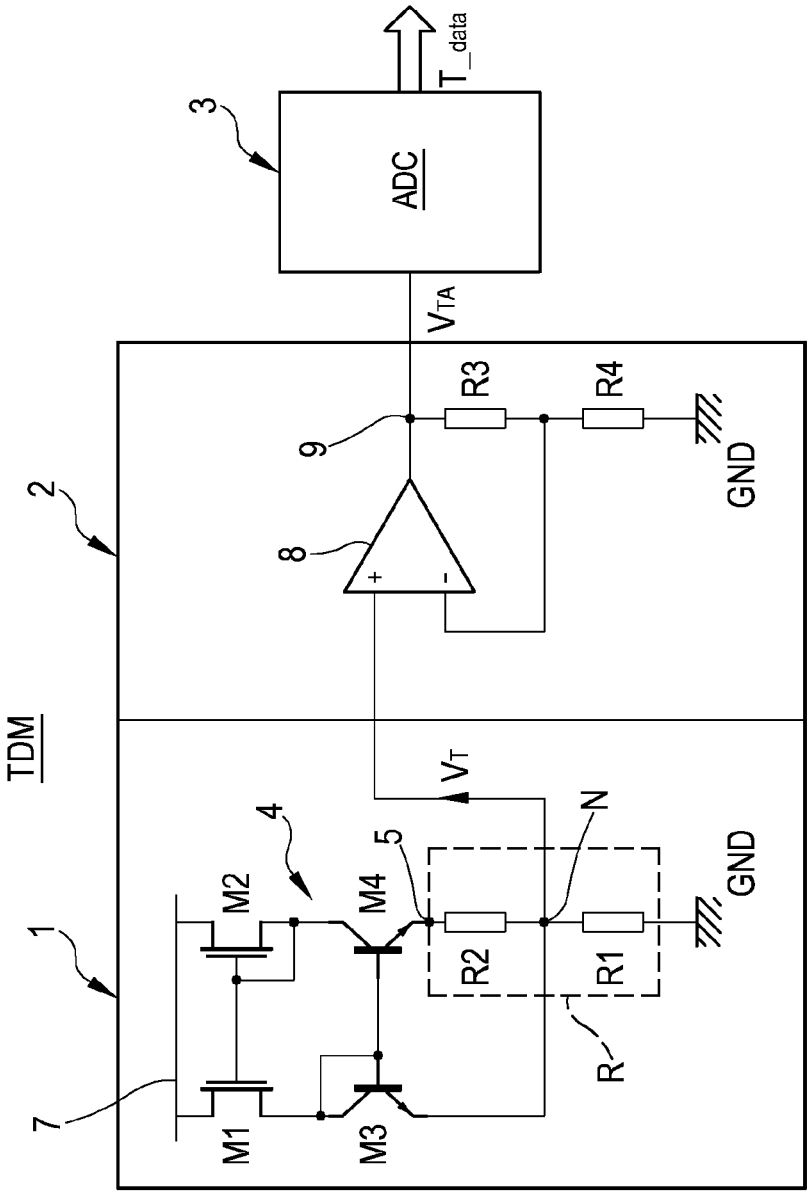

T_data
3
ADC
V_{TA}
2
9
R3
R4
GND
8
+
-
TDM
V_T
4
5
N
M2
M4
GND
1
R2
R1
R
7
M1
M3

FIG.3

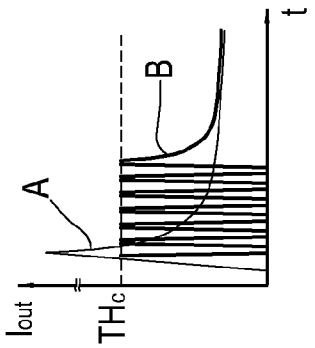

t
B
A
I_{out}
TH_C

FIG.2

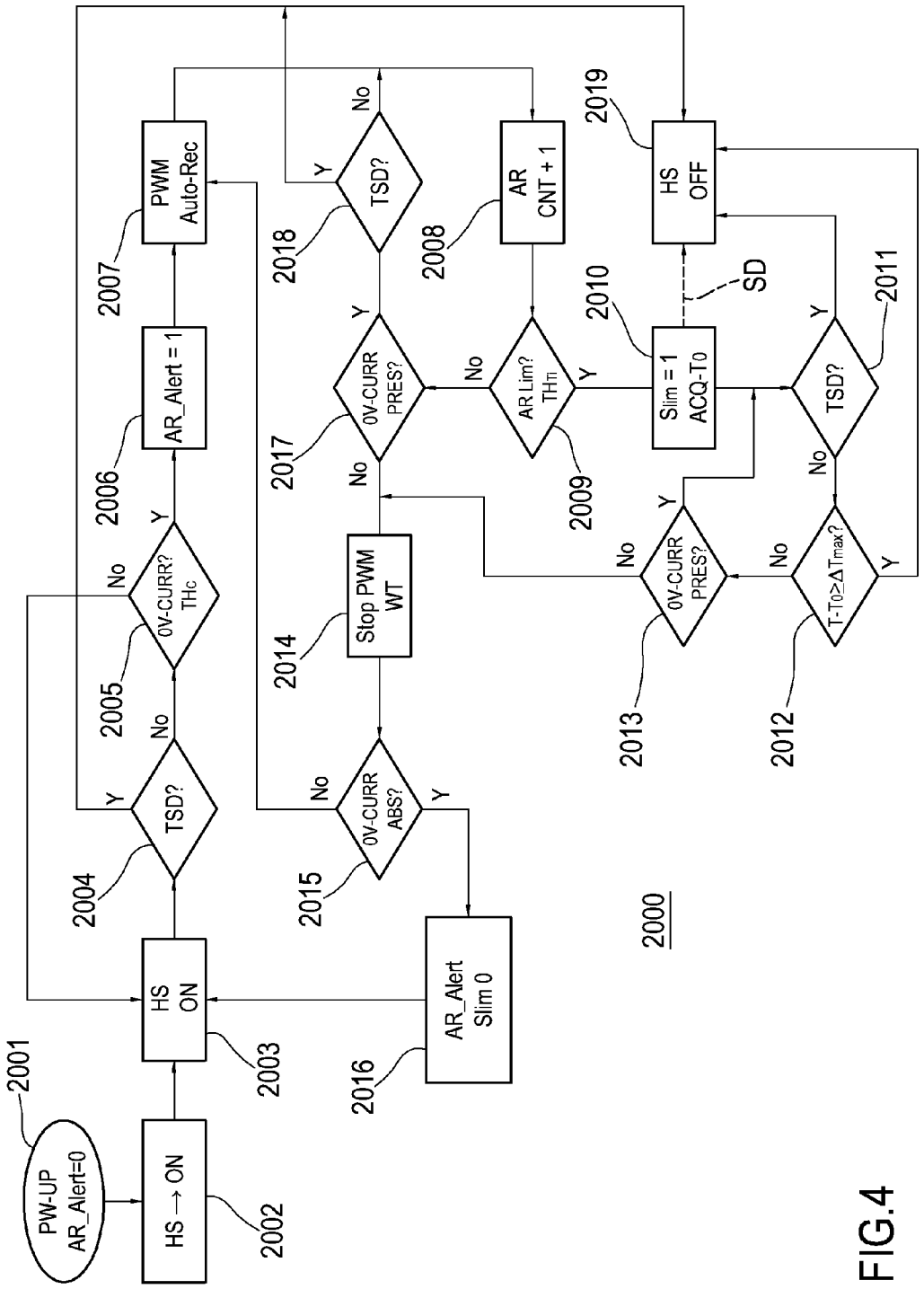

PW-UP
AR_Alert=0
2001
HS → ON
2002
HS
ON
2003
TSD?
2004
0V-CURR?
THc
2005
AR_Alert = 1
2006
PWM
Auto-Rec
2007
TSD?
2018
0V-CURR
ABS?
2015
AR_Alert
Slim 0
2016
Stop PWM
WT
2014
0V-CURR
PRES?
2017
AR Lim?
THn
2009
AR
CNT + 1
2008
0V-CURR
PRES?
2013
Slim = 1
ACQ-T0
2010
TSD?
2011
T-T0≥ΔTmax?
2012
HS
OFF
2019
SD
2000
No
Y

FIG.4

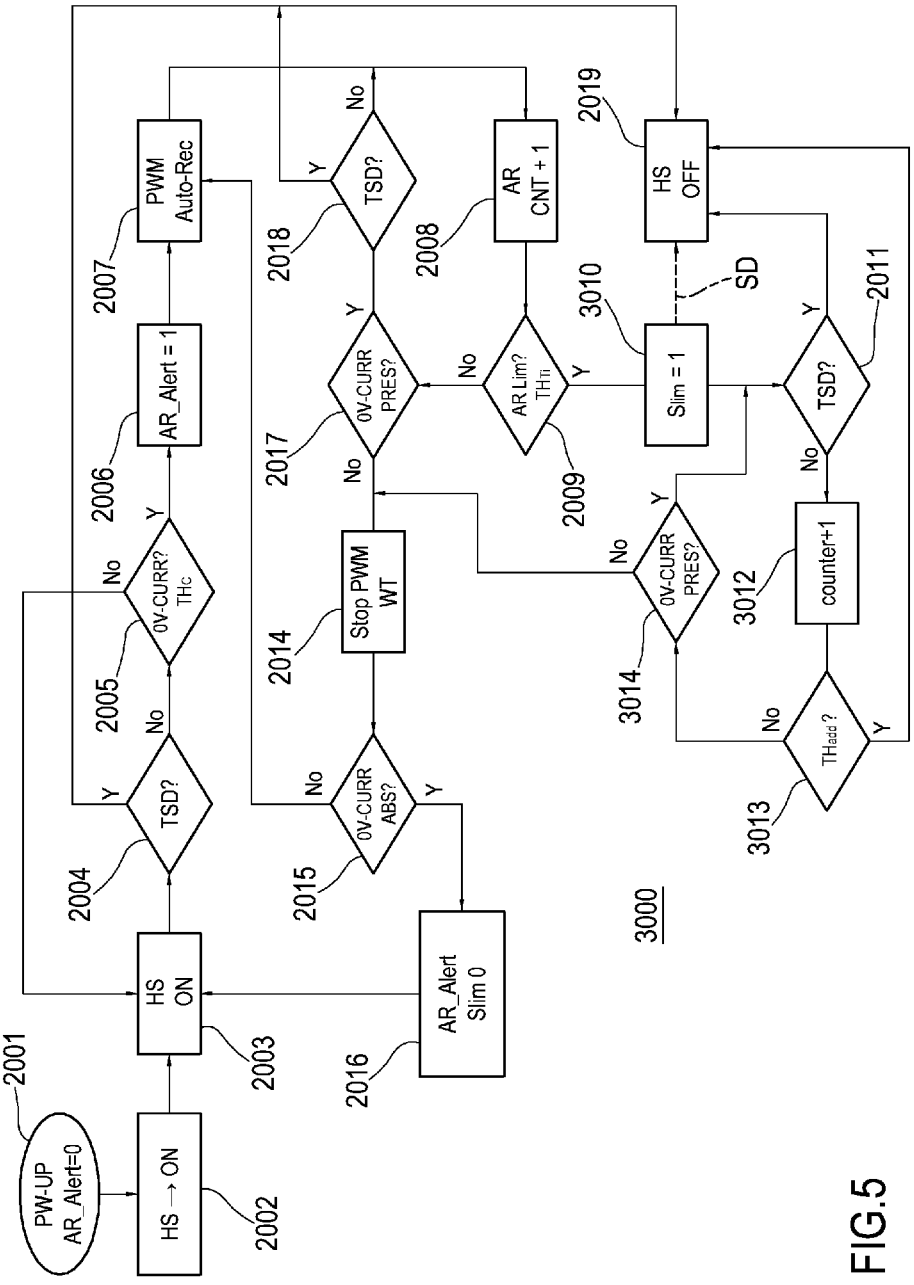

PW-UP
AR_Alert=0
2001
HS → ON
2002
HS
ON
2003
TSD?
2004
0V-CURR?
THc
2005
AR_Alert = 1
2006
PWM
Auto-Rec
2007
AR_Alert
Slim 0
2016
0V-CURR
ABS?
2015
Stop PWM
WT
2014
TSD?
2018
0V-CURR
PRES?
2017
AR
CNT + 1
2008
AR Lim?
THli
2009
HS
OFF
2019
Slim = 1
3010
SD
0V-CURR
PRES?
3014
TSD?
2011
counter+1
3012
THadd ?
3013
3000
Y
N

FIG.5

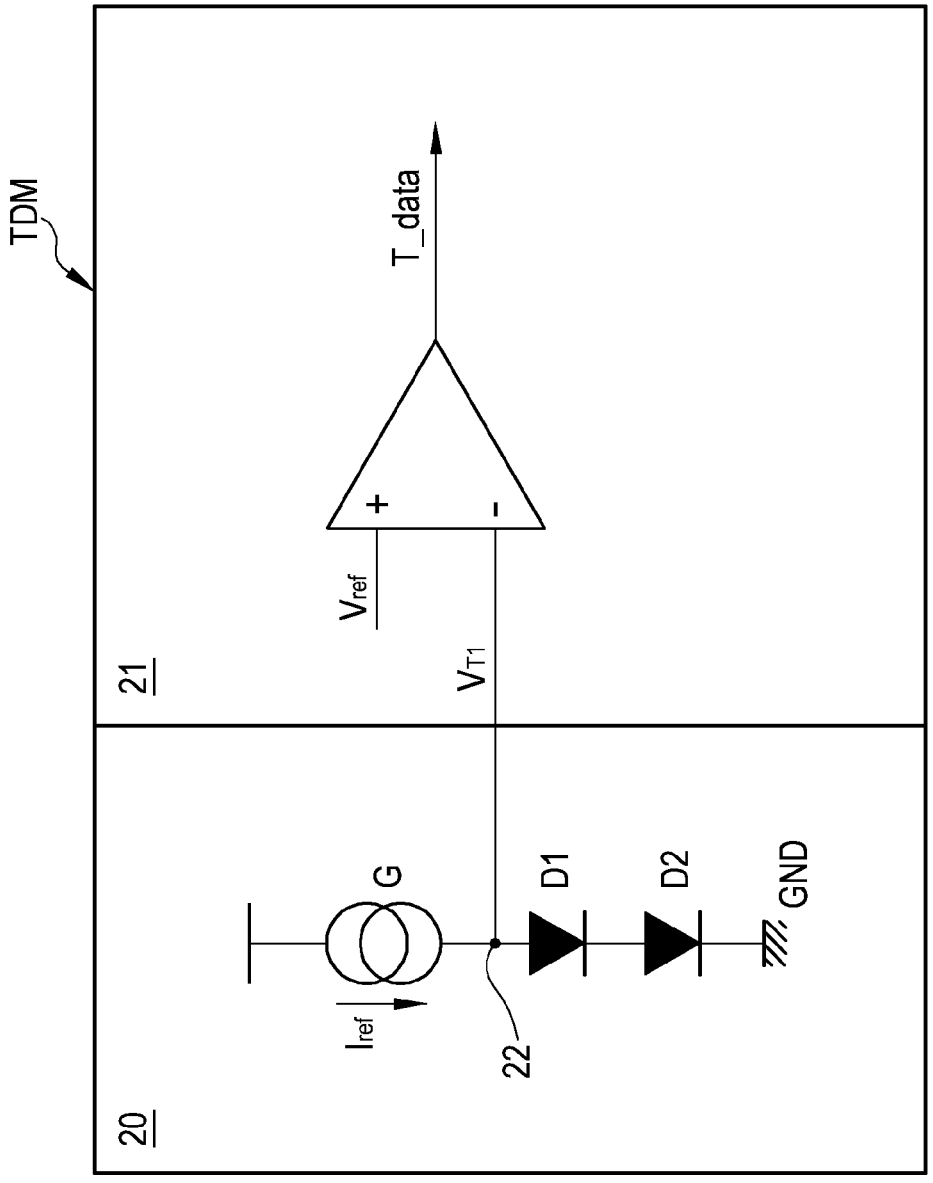


FIG.6

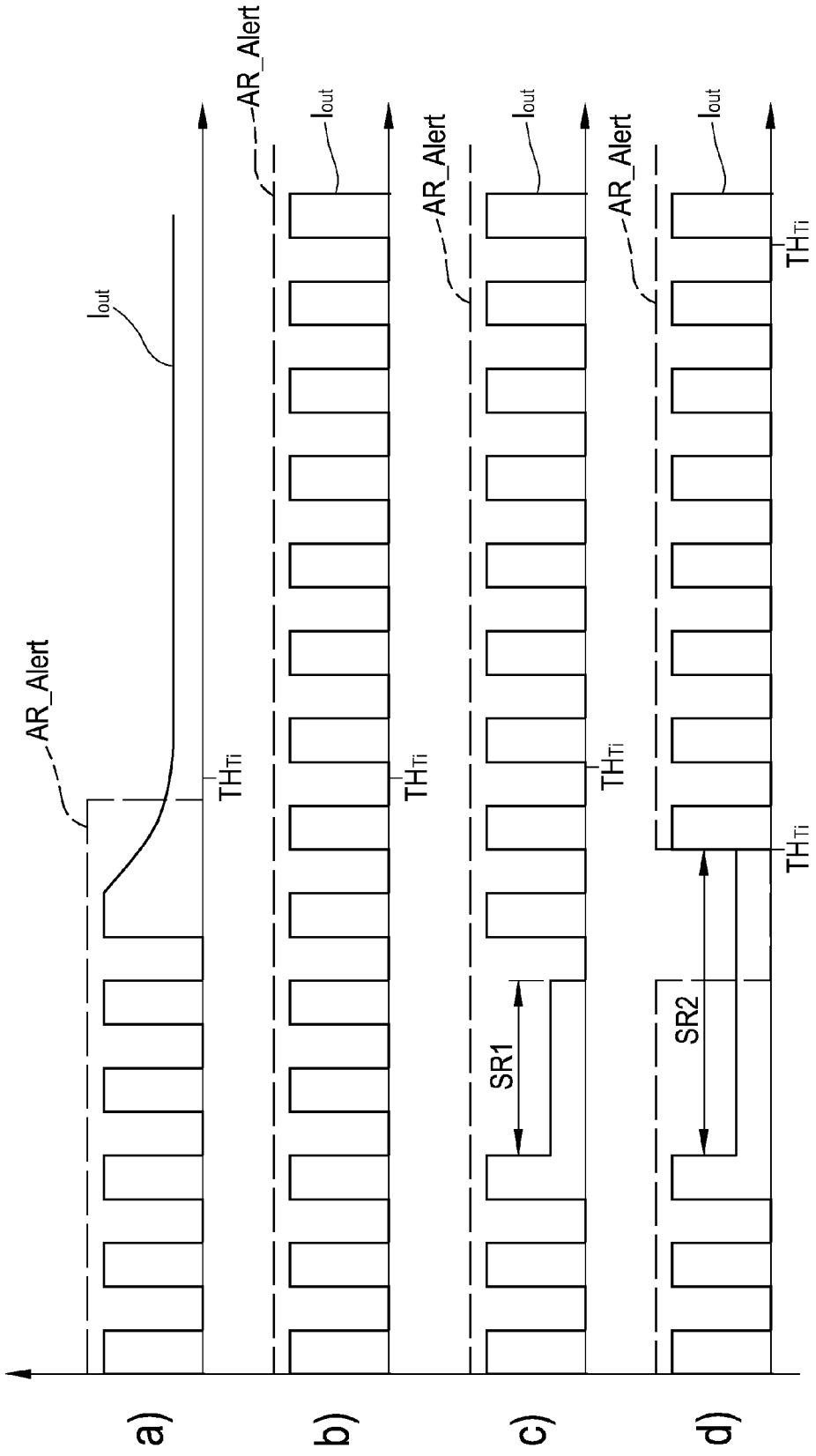


FIG.7

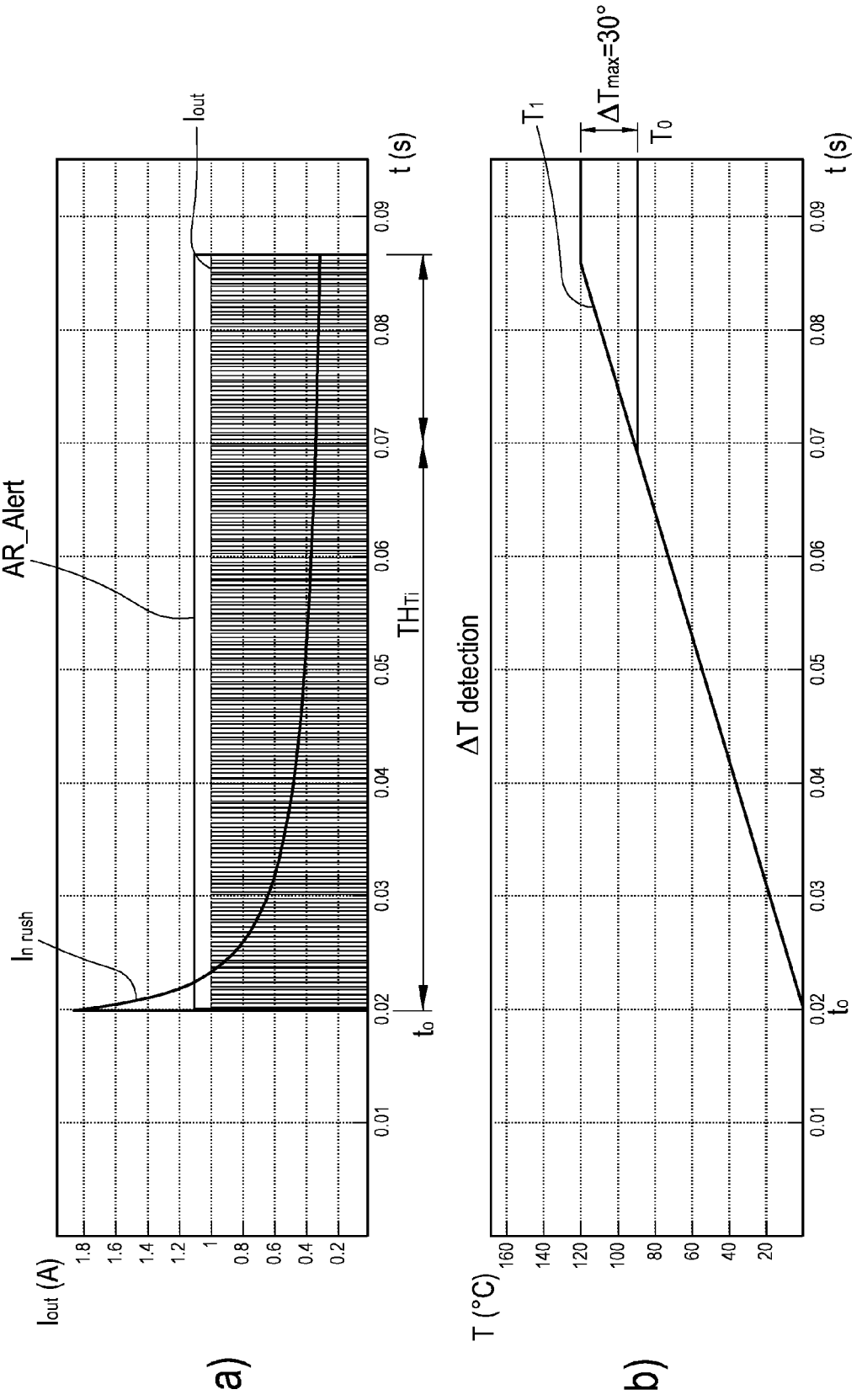

a)
Iout (A)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
t (s)
Iout
AR_Alert
In rush
THTi
to
b)
T (°C)
160
140
120
100
80
60
40
20
ΔT detection
T1
ΔTmax=30°
T0
t (s)
to

FIG.8

ELECTRIC SYSTEM COMPRISING A LOAD DRIVING APPARATUS BY AUTO-RECOVERY MODE, AND METHOD OF OPERATING THE APPARATUS

FIELD OF THE INVENTION

The present description refers to electric load driving techniques which can operate in an auto-recovery mode, known also as "auto-restart". Particularly, the present description refers to the detection and management of short-circuit or overload conditions.

BACKGROUND OF THE INVENTION

There are electric loads requiring for their starting-up or switching-on a current, known as "start-up current", which can reach values which cannot be supplied by some types of power devices adapted to drive loads. Particularly, lateral flow power transistors, such as those manufactured by the BCD technology (Bipolar CMOS DMOS), as opposed to VIPower transistors, may not be capable of sustaining start-up currents of some types of loads, such as those used, for example, on motor vehicles, incandescent lamps or, generally, linear loads. These power transistors, operating as switches, manage the starting-up or switching-on step of the load by applying the auto-recovery mode.

According to the auto-recovery mode, when the current absorbed by the load reaches a predetermined threshold value, the power transistor is switched many times between the switching-off and starting-up, to supply the load with a current having a PWM-type trend and taking a maximum value not greater than the threshold value. The average current supplied to the load in the auto-recovery mode is such as to take it, during a suitable time range and without anomalies, to the standard operation. Indeed, when the maximum current absorbed by the load in a PWM cycle is less than the threshold value, the auto-recovery mode is interrupted and the power transistor remains switched to supply a nominal current to the electric load.

Electronic circuits on which power devices for driving electric load are integrated, offering the capability of operating in an auto-recovery mode, are often managed by a microcontroller outside the integrated circuit, such as, for example, the central unit of a car. Typically, such an outer or external microcontroller is capable of adopting protection provisions entailing the switching-off of the power devices in the presence of particular abnormal conditions.

Moreover, power devices, such as MOSFETs, driving loads have the capability of switching off when non-sustainable junction temperatures are reached, by performing a so-called thermal shut down. The occurrence of abnormal operation conditions are observed in which the power transistor does not supply the load which it was designed for, but instead supplies a short-circuit or an overload.

According to standard driving techniques, the short-circuit or overload conditions leading to an overcurrent state, are managed based on the auto-recovery mode until the occurrence of a temperature increase such as to cause the thermal shut down.

SUMMARY OF THE INVENTION

The Applicant has observed the standard techniques, based on the auto-recovery and thermal shut down, may not be adequate with reference to the management of anomalies caused by an overload and short-circuit. Specifically, standard techniques may not ensure life cycles which are sufficiently long for the power devices supplying electric loads.

Accordingly, a driving apparatus is described herein for an electric load to address the shortcomings of the standard techniques. The driving apparatus may include a power device having a control terminal and an output terminal for an output current to be supplied to the electric load, and a control module configured to drive the power device in an auto-recovery mode, by switching between activation and deactivation for the occurrence of an overcurrent condition, wherein the output current reaches a threshold current. The control module may also evaluate a first time interval; generate a limit signal when the time interval is equal to a time threshold; and drive the power device to a switching-off condition at least as a function of the limit signal. The time interval is between a time wherein the overcurrent condition occurs, and a first time.

BRIEF DESCRIPTION OF THE DRAWINGS

To better understand the embodiments and appreciate their advantages in the following some will be described in an exemplifying non-limiting way, referring to the attached drawings, wherein:

FIG. **1** shows a particular embodiment of an electric system comprising a power device and electric load in accordance with the invention;

FIG. **2** schematically shows the trend of a start-up current of a resistive load and the trend of the output current of the power device as shown in FIG. **1** in the auto-recovery mode;

FIG. **3** shows a particular embodiment of a module for detecting the temperature, usable in the driving apparatus;

FIG. **4** shows, by a flow chart, a first embodiment of a driving method implementable by the driving apparatus of FIG. **1**;

FIG. **5** shows by a flow chart, a second embodiment of a driving method implementable by the driving apparatus of FIG. **1**;

FIG. **6** shows a further particular embodiment of a module for detecting the temperature usable in the driving apparatus for implementing method of FIG. **5**;

FIG. **7** schematically shows different trends of the output current of the power device and a warning signal generated by the driving apparatus, in different possible operative conditions; and

FIG. **8** refers to computer simulations and shows the output current trend of the power device, the trend of a warning signal and trend of the temperature of the power device in the implementation of method of FIG. **4**, in a short-circuit condition.

DETAILED DESCRIPTION OF THE EMBODIMENTS

FIG. **1** shows a particular embodiment of an electric system **1000** comprising an electric load **50** and an apparatus **100** for driving the load **50**. The electric load **50** can be, for example, an additional electric component of the type mountable to a motor vehicle, such as, in particular, an incandescent lamp attachable to a car door, or a blinker attachable to a rearview mirror. The electric load **50** has a terminal connected to the driving apparatus **100** and another terminal connected to a ground terminal GND.

The driving apparatus **100** comprises: a power device HS and control module **200**. More specifically, the power device HS can comprise, for example, a power transistor, such as a MOSFET (Metal Oxide Semiconductor Field Effect Tran-

sistor) as shown in FIG. **1**. In the described particular example, transistor HS comprises a gate terminal G connected to the control module **200**, a source terminal S connected to the electric load **50** for supplying an output current I_{out} and a drain terminal D connected to a supplying terminal for receiving a supply voltage V_{batt} supplied by a battery.

The power transistor HS operates as a switch and, in the described example, is connected according to the high-side configuration, showing the source terminal S connected to load **50**. Particularly, part of control module **200** comprising the MOSFET transistor HS is obtained by integration on a chip made of semiconductor material by BCD technology (Bipolar C-MOS D-MOS) and is of a "side flow" type. Other power devices adapted to drive other loads, not shown in figure, can be integrated on such a chip.

The load **50** is of a type which requires for its starting-up/switching-on a start-up current. For example, for power loads between 5-10 W, the start-up current can reach maximum values between 4 A and 7 A.

The control module **200** is such as to enable driving the power device HS according to the so-called auto-restart mode known also as the auto-recovery mode. According to the auto-recovery mode, the control module **200** performs the following steps:

a) it drives the activation (that is switching on) of the module of the power device HS, and after a switching-on time interval T_{on}, compares the output current value I_{out} to a threshold current TH_c;

b) it deactivates, that is turns off, the power device HS, if an overcurrent condition is detected, in other words, if it is verified the condition wherein the output current I_{out} is equal to or greater than a threshold current TH_c; and

c) it keeps deactivated the power device for an overcurrent filtering time interval T_{off}, and at the end of it the operation goes back to step a).

The deactivation of the power device HS when the current threshold TH_c is reached/exceeded is an action whose object is to protect the integrity of the power device avoiding damage when it is supplying non sustainable currents.

FIG. **2** shows, in an exemplifying way, a first curve A representing the time trend of a start-up current Inrush, as this would be without the auto-recovery mode. Further, FIG. **2** shows, as an example, a second curve B representing the output current I_{out} trend in an implementation of the auto-recovery mode. FIG. **2** refers to an illustrative example of a resistive-type load **50**.

When the output current I_{out} reaches the current threshold TH_c, the control module **200** sets the auto-recovery mode and the power device HS is switched between activation and deactivation. As is apparent from the second curve B, in the auto-recovery mode for a resistive type load **50**, the current Iout takes a PWM-type pulse trend, which can have a predetermined duty cycle set by times T_{on} and T_{off}.

The auto-recovery mode, comprising the power device HS switchings between activation and deactivation as described before, can be employed not only in the load **50** starting-up step, but also in the following operation steps when the conditions occur, except for different operative modes set by control module **200** for managing particular anomalies.

As will be better understood in the following description, the control module **200** is capable of managing anomalies, such as those caused by the presence of a short-circuit or overload at the source terminal S and a temperature increase in the power device HS and/or chip which it is integrated on.

Relating to this, it is observed that an overcurrent condition wherein output current I_{out} exceeds current threshold TH_c, can occur not only because the load **50** can require a particularly high start-up current, but also in the presence of anomalies such as a short-circuit or overload at the source terminal S of power device HS.

Referring again to control module **200**, it is capable of evaluating a time interval T_I between an instant in which output current I_{out} reaches threshold current TH_c, that is when an overcurrent condition is detected, at a present time instant.

Further, the control module **200** is configured to compare this time interval T_I with a time threshold TH_{Ti} and, if the time interval T_I has reached the time threshold, generate a limit signal indicating an overcurrent condition is present for a time interval T_I equal to the time threshold. This limit signal can be used by the control module **200** for driving the power device HS to the switching-off, according to different possible modes that will be described below.

Particularly, referring again to FIG. **1**, the control module **200** comprises a control and drive module DCM and a control unit UC. More particularly, control and drive module DCM comprises a management module DSM and driving circuit DM. Particularly, control and drive module DCM comprises an overcurrent detecting circuit OCD and temperature detecting module TDM.

The control and drive module DCM and the power device HS can be integrated on the same chip by BCD technology, while the control unit UC comprising, for example, a microcontroller **300**, is outside such a chip. The control unit UC is, for example, the main microcontroller of a motor vehicle.

The management module DSM is configured to receive, from the overcurrent detecting module OCD, an overcurrent signal OC, and receive from the temperature detecting module, a temperature measuring signal T_data, representing the temperature reached by the power device HS.

Based upon the overcurrent signal OC the management module DSM is capable of supplying a warning signal AR_Alert indicative of the presence or absence of an overcurrent condition. For example, upon starting up the power device HS, the warning signal AR_Alert takes a logic value 0, and when an overcurrent condition is detected, the warning signal AR_Alert takes a logic value 1.

Moreover, as shown in FIG. **1**, the management module DSM can also supply an enabling signal HS_Enab adapted to deactivate, that is switch off power device HS, or enable its activation. For example, the logic value 1 of the enabling signal HS_Enab corresponds to an enabling of the power device HS activation, while the logic value 0 corresponds to a disabling, that is to a deactivation command, of the power device HS.

The management module DSM implements a control law and is, for example, a finite state machine which can be implemented by a software module executed by a corresponding processing unit, or is embodied by logic implemented by a combinatorial digital machine comprising logic components such as, for example, AND, OR, NOR, NOT gates, and other components such as counters, incrementable registers, flip-flops, and similar devices. The management module DSM may be implemented by a FPGA (Field Programmable Gate Array) board. The management module DSM is timed by a clock signal supplied by an oscillator OSC.

The microcontroller **300** is connected to management module DSM for receiving the warning signal AR_Alert, and further for supplying, to the control and drive module

DCM, a command signal ON/OFF adapted to command the switching-on and off of the power device HS. For example, the logic value 1 of the command signal ON/OFF corresponds to the command for switching on the power device HS, while the logic value 0 corresponds to the command for switching off the power device HS.

The microcontroller **300** is capable of implementing protection provisions involving the switching off of power device HS when particular conditions occur. In these instances, microcontroller **300** can perform the switching-off by taking the command signal ON/OFF to a value equal to 0.

It is noted power device HS comprises a circuit capable of detecting the temperature, managing a thermal protection mode by performing a thermal shut down (TDS) of power device HS itself in case it is detected a temperature value greater than a thermal safety threshold TH_{TSD}.

Management module DSM comprises a logic port LP, for example, of the AND type, configured to receive at its input the enabling signal HS_Enab and command signal ON/OFF, and supply a combined command signal S_c corresponding to an AND logic combination of input signals.

For example, the combined command signal S_c will take a logic value 1 for commanding power device HS to switch on (or equally switch off) when both enabling signal HS_Enab and command signal ON/OFF have taken logic value 1. While combined signal S_c will take logic value 0 for commanding power device HS to switch on (or equally switch off) in any other combination of logic values taken by enabling signal HS_Enab and command signal ON/OFF.

The driving circuit DM is configured to receive at its input combined command signal S_c and supply a corresponding driving signal S_v, such as a voltage, at gate terminal G of power device HS.

The driving circuit DM, which can be of a standard type, can comprise an amplifier enabling to convert combined command signal S_c into a current or voltage S_v adapted to the operation of the power device HS and its switching between activation and deactivation DM. Particularly, such an amplifier included in driving circuit DM increases the electric current associated to the combined command signal S_c (which is for example of few mA) to a value such as to charge the gate capacitance of the MOSFET HS.

Comparing module OCD comprises an operational amplifier having a first input, for example, its non inverting terminal, connected for example, by a sense resistor (not shown) to the drain terminal D of the power device HS for drawing a sense voltage V_{sen} indicating the output current I_{out} flowing through the power device HS and load **50** to the ground terminal GND. The inverting terminal of operational amplifier receives a threshold voltage V_{th} related to the predetermined threshold current TH_c. According to another embodiment, the comparing module OCD is such as to compare a reference electric current with a sensed electric current, for example, by an inductive sensor, from drain terminal D.

Based on the comparison between the sense voltage V_{sen} and the threshold voltage V_{th} performed by the operational amplifier of the overcurrent detecting module OCD, conditions of overcurrent or absence of overcurrent are detected by generating the overcurrent signal OC. For example, such an overcurrent signal OC can take a logic value 1 when an overcurrent condition is detected, while it takes logic value 0 when an overcurrent absence is detected.

According to a first embodiment of the driving apparatus **100**, providing a measurement of a temperature increase in power device HS, temperature detecting module TDM can be embodied as shown in FIG. **3**. According to such a first embodiment, the detecting module **9** comprises a detector **1**, amplifier stage **2**, and an analog-to-digital converter **3**.

The detector **1** is configured to supply at a first output terminal N, a measurement electric voltage T_T proportional to the temperature in the power device HS.

Particularly, the detector **1** comprises a bandgap voltage reference circuit **4** connected to a module receptive to the temperature, comprising a first resistor R**1**, connected between ground terminal GND and first output terminal N, and a second resistor R**2** connected between first output terminal N and second output terminal **5** of bandgap voltage reference circuit **4**. First and second resistors R**1** and R**2** have relative electrical resistances which change as temperature changes.

Bandgap voltage reference circuit **4**, a conventional one per se, comprises a first MOSFET transistor M**1** and second MOSFET transistor M**2** forming a first current mirror. First current mirror M**1**-M**2** is connected to a supply terminal **7** and to a second current mirror formed by a third transistor M**3** and a fourth transistor M**4**, both, particularly, of the bipolar type. The emitter terminal of third transistor M**3** is connected to first output terminal N, while the emitter terminal of fourth transistor M**4** is connected to second output terminal **5**.

Second mirror current M**3**-M**4** is configured so that the fourth transistor M**4** supplies to a second output terminal **5** a current equal to the one supplied by third transistor M**3** to first output terminal N multiplied by a factor A. For example, A is between 1 and 10, but could be also greater than 10.

By suitably balancing the values of resistances of the first and second resistors R**1** and R**2**, the detector **1** operates as a voltage reference at a temperature of 0° K, by generating for this temperature value a measurement electric voltage V_T equal, for example, to 1.22 V. Factor A, that is the ratio between currents in current mirror M**3**-M**4**, enables setting the measurement sensitivity. For example, by selecting factor A equal to 10, for each increase of 1° K, there is a corresponding increase of 0.2 mV in the measurement electric voltage V_T.

Amplifier stage **2** amplifies the measurement electric voltage V_T and supplies at third output terminal **9** an amplified measurement electric voltage V_{TA}. For example, the amplifier stage **2** can comprise an operational amplifier **8** having a feedback configuration. The operational amplifier **8** has its corresponding non inverting terminal connected to a first output terminal N for receiving the measurement electric voltage V_T, and the corresponding inverting terminal is connected to the third output terminal **9** through a third resistor R**3**, which, in turn, is connected to the ground terminal GND by a fourth resistor R**4**.

Third output terminal **9** is connected to an input of the analog-to-digital converter **3** configured to convert the amplified measurement electric voltage V_{TA} into a temperature measurement signal T_data which, in a digital form, represents the temperature measured value reached by the power device HS.

FIG. **4** shows, by a flow chart **2000**, a method of operating the driving apparatus **100**, and therefore shows also the operative modes of the management module DSM and microcontroller **300**, also in the particular case wherein there are anomalies caused by a short-circuit, overload with temperature increments.

The method of FIG. **4** refers to the particular embodiment of driving apparatus **100** which provides a measurement of

the temperature increase, and which uses the temperature detecting module TDM as described with reference to FIG. **3**.

In a first step **2001** (PW_UP, AR_Alert=0), the control module **200** is connected to the supply terminal for receiving the supply voltage V_{batt}, and warning signal AR_Alert takes logic value 0; the value of such warning signal AR_Alert is also stored in a corresponding register in the microcontroller **300**.

In a second step **2002** (HS→ON), the microcontroller **300** takes the command signal ON/OFF to a logic value 1, therefore commanding the power device HS to switch on. Further, the management module DSM supplies an enabling signal HS_Enab of logic value 1, so that the driving circuit switches on the power device HS, as shown by a third step **2003** (HS ON).

In a fourth step **2004** (TSD?) upon the switching on, the temperature of the chip in which the power device HS is integrated can exceed or not the thermal safety threshold TH_{TSD}. In an affirmative case (branch Y), the power device HS is immediately switched off, and a nineteenth step **2019** (HS OFF) is reached.

If the thermal safety test is negative (branch No), the command signal ON/OFF keeps logic value 1 and the management module DSM executes, in a fifth step **2005** (OV-CURR ?), a test regarding the presence or absence of an overcurrent.

In such fifth step **2005**, the management module DSM reads the overcurrent signal value OC and if this value has a logic value 0 (overcurrent is absent), it keeps the enabling signal HS_Enab to a logic value 1, by keeping activated the power device HS and, in other words, operation returns to third step **2003**.

When the management module DSM detects from the overcurrent signal OC the presence of an overcurrent (branch Y), it switches the warning signal AR_Alert from a logic value 0 to a logic value 1, in the sixth step **2006** (AR_Alert=1).

As explained before, the presence of overcurrent can be due to the start-up current required by the load **50** or by abnormal conditions of a short-circuit or overload.

Once the overcurrent condition has been detected, there is activated, in a seventh step **2007** (PWM Auto-Rec) the auto-recovery mode managed by the management module DSM by the enabling signal HS_Enab which switches from logic value 1 to 0 and viceversa, by deactivating and activating the power device HS according to a timing set by selected values of switching-on time interval T_{on} and the filtering time interval of overcurrent T_{off}.

The microcontroller **300**, receiving warning signal AR_Alert, is informed about the performed detection of the overcurrent and about the auto-recovery mode activation.

Moreover, as shown in an eighth step **2008** (AR CNT+1), the management module DSM performs by its counter a calculation of the time interval T_I between an instant in which the overcurrent condition has been detected (by enabling the auto-recovery mode) and a present instant, for example, by a clock signal supplied by an oscillator OSC.

For each increase of one unit of the counter, see ninth step **2009** (AR Lim ?), the value obtained of the time range T_I is compared, by the management module DSM, with the time threshold TH_{Ti}.

In case the time range T_I is equal to time threshold TH_{Ti} (branch Y), the method proceeds to a tenth step **2010** (Slim=1, ACQ–T_0), in which the management module DSM supplies the limit signal S_{lim} with a logic value equal, for example, to 1, to the microcontroller **300**, indicating that the time threshold TH_{Ti} has been reached.

Moreover, in tenth step **2010**, the management module DSM acquires from the temperature detecting module TDM, an initial temperature value T_0 representing the temperature of the power device HS when it is detected that the time threshold TH_{Ti} has been reached.

It is observed that, as shown in FIG. **4** by a dotted branch SD, the method can provide, according to a particular example, that the microcontroller **300** switches off the power device HS and/or the whole chip on which the power device is integrated, by preventing the auto-recovery mode, arriving in this way to the nineteenth step **2019** (HS OFF), as soon as it receives the limit signal S_{lim} having a logic value equal to 1.

Indeed, the continuation of the auto-recovery condition for a time range equal to the time threshold TH_{Ti} can be considered as indicative of the presence of an anomaly which can lead to a failure in the power device HS.

Returning back to tenth step **2010**, the method continues to an eleventh step **2011**, in which the thermal safety test is repeated in the same way as described with reference to the fourth step **2004**.

If the answer of the safety thermal test is positive (branch Y), the power device HS switches off, so operation reaches the nineteenth step **2019** (HS OFF) and prevents the auto-recovery mode.

In case the answer (branch No) of the thermal safety test is negative, the method preferably arrives to twelfth step **2012** ($T-T_0>\Delta T_{max}$?) wherein the management module DSM acquires from the temperature detecting module TDM a current value T of the power device HS temperature, and computes the temperature increase $T-T_0$, with respect to the beforehand acquired initial temperature T0.

Moreover, in the twelfth step **2012**, the management module DSM compares the temperature increase $T-T_0$ with a thermal variation threshold ΔT_{max} for determining if the temperature increase $T-T_0$ has reached or exceeded the thermal variation threshold ΔT_{max}.

In the affirmative case, the management module DSM, by switching enabling signal HS-Enab to a logic value 0, commands the power device HS to switch off, so operation reaches the nineteenth step **2019**, preventing also the auto-recovery mode.

It is noted that the power device HS switching-off, which follows the twelfth step **2012**, is necessary and performed by the management module DSM independently from the external microcontroller **300**. Moreover, from a time point of view, the switching-off commanded by the management module DSM can substantially occur before the thermal switching-off (steps TDS, Y), after the thermal safety test.

In case, during the twelfth step **2012**, the reaching of thermal variation threshold ΔT_{max} (branch No) is not detected, there is a thirteenth step **2013** (OV-CURR PRES ?) wherein the management module DSM evaluates again the presence of an overcurrent, by reading the value taken by the overcurrent signal OC supplied by the overcurrent detecting module OCD.

If the overcurrent condition continues (branch Y, step **2013**), the method returns to the eleventh step **2011** for performing again the safety thermal test.

In the negative case (branch No) wherein the overcurrent condition has been removed, the method preferably continues to a fourteenth step (**2014** (Stop PWM-WT) wherein the management module DSM, by the enabling signal HS_Enab, interrupts the auto-recovery mode and takes a waiting state.

For example, this waiting state has a duration equal to two times the period of the overcurrent signal OC acquisition by the management module DSM. At the end of the waiting period, in a fifteenth step **2015** (OV-CURR ABS ?), the management module DSM performs a further test for evaluating if the overcurrent state is still absent. In the negative case (branch No), that is when the overcurrent condition appears again, the method returns to the seventh step **2007** wherein the auto-recovery mode persists.

This fourteenth step **2014**, comprising a waiting period before performing a test about an overcurrent presence, has the advantage of avoiding or reducing the possibility that the presence of an intermittent-type short-circuit could be mistaken for a series of independent events, causing in turn a delay in the temperature T_0 acquisition.

In the positive case (branch Y, step **2015**), that is when overcurrent condition is still absent, in a sixteenth step **2016** (AR_Alert, S_{lim}, 0), the management module DSM resets to a logic value 0 both the warning signal AR_Alert and the limit signal S_{lim}. The method therefore continues to a third step **2003** wherein power device HS is switched on.

The sixteenth step **2016** corresponds to the situation wherein the auto-recovery mode is successful, and, therefore, there is a correct supply of load **50** and possible abnormal conditions (short-circuit or overload) are absent or have been removed.

Returning to the ninth step **2009**, if the time interval T_I is less than time threshold TH_{Ti} (branch No), the method continues to a seventeenth step **2017** (OV-CURR PRES?), wherein the management module DSM evaluates if the overcurrent condition is still present or not.

If the overcurrent condition is not present (branch No), from seventeenth step **2017**, the method provides for the passage to the already described fourteenth step **2014**.

Instead, if in the seventeenth step **2017**, the management module DSM detects (branch Y) the presence of an overcurrent condition, the method provides for the passage to an eighteenth step **2018** (TSD ?), wherein the safety thermal test is performed, as described before.

If such a safety thermal test detects that the temperature of the chip including the power device HS is less than the safety thermal threshold TH_{TSH} (branch No), the method continues to the above described eight step **2008**.

Instead, if such safety thermal test of eighteenth step **2018** detects that the safety thermal threshold TH_{TSD} has been reached (branch Y), the power device HS and devices present on the same chip are switched off, and the method continues to nineteenth step **2019**.

It is noted that the driving method **2000**, previously described with reference to FIG. **4**, provides for, among other things, the switching-off of the power device HS when an evaluation of the temperature increase $T-T_0$ during the auto-recovery mode exceeds a predetermined thermal variation threshold ΔT_{max} (see twelfth step **2012**). For example, such a threshold could be equal to 30° C.

With reference to the driving method of FIG. **4**, such a temperature increase evaluation is performed based upon the temperature present values taken by the power device HS, measured by the temperature detecting module TDM of FIG. **3**.

According to another embodiment, the temperature increase evaluation during the auto-recovery mode can be performed by an estimate, and not by a direct measurement of temperature. To this end, FIG. **5** shows a further operation flowchart **3000** for a method of the driving apparatus **100**. This further operation method comprises some steps similar or identical to the ones described with reference to the flowchart **2000** of FIG. **4** and which are indicated in FIG. **5** by the same reference numerals.

Particularly, according to the flowchart **3000** of FIG. **5**, in step **2009**, when the time range T_I is equal to the time threshold TH_{Ti} (branch Y), then an information step **3010** follows wherein the management module DSM supplies the limit signal S_{lim} to the microcontroller **300**, having a logic value for example equal to 1, indicating that time threshold TH_{Ti} has been reached.

After the microcontroller **300** has performed the safety thermal test in the eleventh step **2011** and has verified (branch No) that the temperature has not reached the thermal safety threshold T_{TSD}, further flowchart **3000** provides for a further counting step **3012**. In this further counting step **3012**, the management module DSM evaluates (for example by counting clock pulses) an additional time interval T_{add} between the instant wherein the reaching of time threshold TH_{Ti} has been detected and an instant of current time Ti.

In a following time comparing step **3013** (TH_{add} ?), the management module DSM compares the additional time interval T_{add} with a further time threshold TH_{Tadd}.

If the additional time interval T_{add} is less than the further time threshold TH_{Tadd}, a step verifying the presence of overcurrent **3014** (OV-CURR PRES ?) is performed. In the positive case (branch Y), the further flowchart **3000** continues to the above described eleventh step **2011**. In the negative case (branch No), that is without an overcurrent condition, the further method continues to the above described fourteenth step **2014**.

Returning to the time comparing step **3013**, if the further time threshold TH_{Tadd} has been reached (branch Y), the management module DSM can command, by the enabling signal HS_Enab, the power device HS to be deactivated, reaching in this way the nineteenth step **2019**.

It is observed the time comparing step **3013**, based on a further time threshold TH_{Tadd}, is an estimate of a temperature increase in the power device HS when the latter remains in the auto-recovery mode. Further time threshold TH_{Tadd} can be determined based on a thermal pattern of power device.

It is also observed in the time comparing step **3013**, the module DSM can, according to a particular embodiment, subordinate the deactivation of the power device HS to reaching of a maximum temperature value T_{max} from the same power device. Alternatively, in place of the time comparing step **3013**, the deactivation of the power device HS can be commanded when the management module DSM detects the maximum temperature value T_{max} has been reached.

It is observed that the detection of the maximum temperature value T_{max} reaching can be performed, according to a particular example, by a temperature detecting module TDM configured as shown in FIG. **6**, more simple and economical than the one shown in FIG. **3**.

The temperature detecting module TDM of FIG. **6** comprises a further detector **20** and comparator **21**. Further detector **20** comprises a current reference circuit G (standard per se and, for example, based on a further bandgap voltage reference), configured to inject a reference current T_{ref} in an output node **22**. Output node **22** is connected to a further module sensitive to the temperature, comprising a first diode D**1** and second diode D**2**. First diode D**1** has a first anode connected to the output node **22**, and a first cathode connected to a second anode of second diode D**2**, having a second cathode connected to ground terminal GND. First and second diodes D**1** and D**2** have corresponding electric resistances which vary as temperature varies; therefore, as

temperature varies the electrical voltage at output node **22** also varies, with a negative thermal coefficient.

During the operation, at the output node **22** a further measurement electric voltage V_{T1} is present indicating the temperature reached by the power device HS.

The comparator **21**, standard per se, is configured to receive the further measurement electric voltage V_{T1} at its inverting terminal, and compare it with a reference voltage V_{ref} selected based on the maximum temperature value T_{max}. Output signal T_data will take two logic levels: one indicating that measured temperature is less than the maximum temperature value T_{max}, and a further value indicating that the exceeded temperature has reached a maximum temperature value T_{max}

Moreover, it is preferably noted, both for method of flowchart **2000** and the further method of flowchart **3000**, the thermal safety test, performed by the same power device HS, is always enabled and is not just performed in the particular fourth **2004**, eleventh **2011**, eighteenth steps **2018**.

FIG. **7** shows the trend of the warning signal AR_Alert and output current I_{out} in different operative particular situations.

FIG. **7***a*) refers to a situation where an overcurrent condition occurs, and, therefore, the warning signal AR_Alert is taken to a logic value and the auto-recovery mode is performed by generating some PWM cycles for the output current. FIG. **7** also shows the time threshold TH_{Ti} from which the temperature monitoring is activated according to flowchart **2000** (FIG. **4**) or the temperature estimate based on a clock pulses count according to further flowchart **3000** (FIG. **5**).

In the example of FIG. **7***a*), the output current I_{out}, before reaching time threshold TH_{Ti}, decreases below a predetermined threshold current TH_c, and therefore goes out from the overcurrent condition, the warning signal AR_Alert takes again a logic value 0, therefore the auto-recovery mode is no longer performed, but just a standard supplying of load **50**. This situation can occur during the step of switching on the load **50** which does not have anomalies and requires a start-up current.

The example of FIG. **7***b*) refers to a permanent short-circuit situation, wherein the warning signal AR_Alert remains at logic level 1 also after time threshold TH_{Ti} has been exceeded.

FIG. **7***c*) refers to a first example of an intermittent short-circuit condition. As observed from FIG. **7***c*), in a first suspension time internal SR**1**, the short-circuit is suspended, and, in other words, an overcurrent condition does not occur. According to what has been described with reference to fourteenth step **2014** of operation flowcharts **2000** and **3000**, since such first suspension interval SR**1** is less than the one between two overcurrent measurement events, the warning signal AR_Alert is held at logic value 1.

FIG. **7***d*) refers to a second example of an intermittent short-circuit condition. As it is known from FIG. **7***d*), in a second suspension time interval SR**2**, the short-circuit is suspended, and, in other words, an overcurrent condition does not occur. According to what has been described with reference to fourteenth step **2014** of operation flowcharts **2000** and **3000**, since such a second suspension range SR**2** is greater than the one between the two overcurrent measurement events, the warning signal AR_Alert is taken to a logic value 0. Afterwards, since there is again an overcurrent condition, the warning signal AR_Alert is again taken to logic value 1, and the time threshold TH_{Ti} is set forward.

FIG. **8***a*) shows a time trend of the output current I_{out} and warning signal AR_Alert when a computer simulates the operation of the electric system **1000** configured for an electric load of 5 W, but in a short-circuit situation.

The 5 W electric load would show a start-up current Inrush shown in FIG. **8***a*). Upon switching on of the control module **200** and power device HS (at time to), an overcurrent condition is detected and consequently the warning signal AR_Alert is taken to a logic value 1, and the auto-recovery mode starts with an output current I_{out} taking a trend of the PWM type. Curve T1 of FIG. **8***b*) shows the increasing trend of the power device HS temperature in such a situation.

The overcurrent condition and therefore the logic value 1 of the warning signal AR_Alert persists until the time threshold TH_{Ti} is equal, in the computer simulation, to 50 msec (located in FIG. **8***a*) the at instant 0.07 sec. Upon reaching the time threshold TH_{Ti}, the temperature T_0 is acquired and the temperature monitoring T is activated.

Upon reaching thermal variation threshold ΔT_{max} equal, by the computer simulation, to 30° C., after about 15 msec, the power device HS is switched off, without continuing to the auto-recovery mode, and the warning signal AR_Alert is taken to logic value 0.

ADVANTAGES

The electric system **1000** and driving apparatus **100** have different advantages compared with the prior art. More specifically, the driving apparatus **100** is particularly strong to anomalies such as short-circuits or overloads, and offers great safety in the presence of temperature increases.

Particularly, the generation of signals, such as warning signal AR_Alert and limit signal S_{lim}, indicating the implementation of auto-recovery mode, and duration of such mode, enables both the management device DSM and microcontroller **300** to switch off the power device before an intervention of the power device HS protection functionality based on the temperature detections (thermal shut down).

However, the management module DSM does not prevent a switching-off of the power device HS required by the microcontroller **300**, ensuring in this way the maximum protection against thermal increases.

The possibility of the management device DSM causing the power device HS switching-off independently from the microcontroller **300**, offers a particular protection against overloads and short-circuits, also in case of microcontroller **300** malfunctions.

Moreover, the particular embodiment providing a waiting time between two overcurrent tests before exiting the auto-recovery mode, is particularly advantageous for correctly detecting also intermittent short-circuits.

Pursuant to tests performed by the Applicant, it was noted the driving apparatus **100** enables a substantial increase of power device HS duration compared with what occurred with prior art devices. Indeed, while, according to the prior art, using lateral-flow power devices, typical of BCD technology, power device duration is about of one million cycles. In contrast, with the control apparatus **200**, the power device life reaches about seven millions cycles, and therefore a life of lateral-flow power devices is comparable to the life of VIPower devices.

That which is claimed is:

1. A driving apparatus for an electric load comprising:

a power device having a control terminal and an output terminal for an output current to be supplied to the electric load; and

a control module configured to

drive said power device in an auto-recovery mode, by switching between activation and deactivation responsive to an overcurrent condition wherein the output current reaches a current threshold, with said power device remaining in a fully on state when the output current reaches the current threshold,

evaluate a first time interval between a time when the overcurrent condition occurs, and a first time,

generate a limit signal when the time interval is equal to a time threshold, and

drive said power device to a switching-off condition at least as a function of the limit signal;

said control module comprising a control and drive module configured to

evaluate a temperature increase of said power device associated with a second time interval and between generating the limit signal and a second time, and

generate a first signal for switching off said power device when the evaluated temperature increase reaches a first threshold temperature.

2. The driving apparatus according to claim **1**, wherein said control and drive module further comprises a thermal detecting module configured to measure at generating the limit signal, a first temperature of said power device, and a second temperature of said power device associated with the second time.

3. The driving apparatus according to claim **2**, wherein said control and drive module is further configured to:

evaluate a temperature increase based on a difference between the first and second temperatures; and

generate the first signal for switching off said power device when the temperature increase reaches the first threshold value indicative of a first threshold temperature.

4. The driving apparatus according to claim **3**, wherein said control and drive module is configured to:

evaluate the temperature increase based on evaluating a third time interval between generating the limit signal, and a third time; and

generate the first switching-off signal when the third time interval reaches the first threshold value indicating a further time threshold.

5. The driving apparatus according to claim **4**, wherein said control module comprises a control device distinct from said control and drive module, and configured to:

supply a signal for switching on said power device, to said control and drive module; and

supply a second switching-off signal to said control and drive module to cause the switching off of said power device for conditions detectable by said control device.

6. The driving apparatus according to claim **5**, wherein said power device comprises a safety thermal module configured to:

detect a third temperature associated with said power device; and

cause the switching-off of said power device when the third temperature reaches a second temperature threshold.

7. The driving apparatus according to claim **6**, wherein said control and drive module is configured to generate said first switching-off signal independently from generating the second switching-off signal by the control device and independently from the switching-off caused by the safety thermal module.

8. The driving apparatus according to claim **1**, wherein said control module further comprises a module for detecting an overcurrent condition coupled to said power device, and configured to supply an overcurrent signal adapted to assume a first value indicating that the output current has reached or exceeded the current threshold, and a second value indicating that the output current is less than the current threshold.

9. The driving apparatus according to claim **8**, wherein said control module is configured to generate a warning signal adapted to:

take a first digital value when the overcurrent signal takes the first value, and indicate application of the auto-recovery mode; and

take a second digital value when overcurrent signal takes the second value, and indicate that the auto-recovery mode has not been applied.

10. The driving apparatus according to claim **9**, wherein said control module comprises a control device; and wherein said control module is configured to supply the warning signal to said control device.

11. The driving apparatus according to claim **1**, wherein said control module is configured to:

perform a plurality of checks of the overcurrent condition when said power device is in the auto-recovery mode;

drive said power device outside the auto-recovery mode for driving it in a standard load supplying mode when said plurality of overcurrent checks generate negative results.

12. The driving apparatus according to claim **11**, wherein said control module is further configured to perform the plurality of checks according to the following modes:

performing a first check of the overcurrent condition having a negative result;

waiting a pause time wherein said power device is taken outside the auto-recovery mode, and operating in the standard load supplying mode;

performing a second check of the overcurrent condition having negative result; and

holding said power device in the standard load supplying mode.

13. The driving apparatus according to claim **1**, wherein at least one of the time threshold and first threshold is selected for detecting at least one of a short-circuit condition and an overload condition.

14. The driving apparatus according to claim **1**, wherein said control and drive module further comprises:

a first logic port configured to receive the first switching-off signal and the second switching-off signal, and generate a combination signal;

a driving module for said power device, configured to receive the combination signal, and generate a driving signal for said power device to drive its activation and deactivation; and

a management module configured to receive an overcurrent signal, and generate a warning signal and first switching-off signal.

15. The driving apparatus according to claim **14**, wherein said management module comprises a state machine.

16. The driving apparatus according to claim **1**, wherein said power device comprises a high-side configured MOSFET and said control module is implemented by bipolar CMOS DMOS technology.

17. An electronic device comprising:

a power device configured to generate an output current; and

a controller coupled to said power device and configured to

drive said power device in an auto-recovery mode, by switching between activation and deactivation based upon an overcurrent condition, with said power device remaining in a fully on state when the overcurrent condition is reached,

evaluate a first time interval between when the overcurrent condition occurs and a first time,

generate a limit signal when the time interval is equal to a time threshold, and

drive said power device to a switching-off condition based upon the limit signal;

said controller is configured to

evaluate a temperature increase of said power device associated with a second time interval and between generating the limit signal and a second time, and

generate a first signal for switching off said power device when the evaluated temperature increase reaches a first threshold temperature.

18. The electronic device according to claim **17**, wherein said controller is configured to measure at generating the limit signal, a first temperature of said power device, and a second temperature of said power device associated with the second time.

19. The electronic device according to claim **18**, wherein said controller is configured to:

evaluate a temperature increase based on a difference between the first and second temperatures; and

generate the first signal for switching off said power device when the temperature increase reaches the first threshold value indicative of a first threshold temperature.

20. The electronic device according to claim **18**, further comprising an electric load coupled to said power device.

21. The electronic device according to claim **20**, wherein said electric load comprises an electric component attachable to a motor vehicle.

22. A method for driving an electric load comprising:

driving a power device coupled to the electric load in an auto-recovery mode, by switching between activation and deactivation based upon an overcurrent condition, with the power device remaining in a fully on state when the output current reaches the current threshold;

evaluating a first time interval between when the overcurrent condition occurs and a first time;

generating a limit signal when the time interval is equal to a time threshold;

driving the power device to a switching-off condition based upon the limit signal;

evaluating a temperature increase of the power device associated with a second time interval and between generating the limit signal and a second time; and

generating a first signal for switching off the power device when the evaluated temperature increase reaches a first threshold temperature.

23. The method according to claim **22**, further comprising measuring at generating the limit signal, a first temperature of the power device, and a second temperature of the power device associated with the second time.

24. The method according to claim **23**, further comprising:

evaluating a temperature increase based on a difference between the first and second temperatures; and

generating the first signal for switching off the power device when the temperature increase reaches the first threshold value indicative of a first threshold temperature.

25. The method according to claim **22**, wherein the electric load comprises an electric component attachable to a motor vehicle.

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